EXPERIMENTAL AND NUMERICAL INVESTIGATION OF COMPRESSION IGNITION ENGINE PERFORMANCE WITH GREEN FUELS

A brief outline of the area of research work proposed to be carried out in pursuance of the requirements for the award of the degree of

Doctor of Philosophy

Submitted by

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1. INTRODUCTION

All of the human beings are inhaling air every day which mainly comprises of 78% nitrogen and 21% oxygen and small amount of suspended particles which have vast impact on human health. Quality of air is degrading day by day due to the venomous gases and particulate matter of highly toxic substances.

Rapid growth in automobile vehicle industry in the world has resulted in increase of exhaust emissions to the environment. Vehicular emissions such as particulate matter (PM), hydrocarbon (HC), carbon dioxides (CO_2), carbon monoxides (CO) and nitrogen oxides (NO_x) are enormously responsible for the air quality deterioration. Also, it has been reported that an increase in average global temperature by 2°C will cause in death of billions of people. [8].

1.1 Status of Transportation Sector

Transportation system has a great importance for social and economic development of any country. The rising issue for transportation sector is the energy which mainly fulfilled by gasoline and diesel fuel. Globally 1.1% of average energy consumption is increased in the transportation sector every year. The transportation sector accounts for the largest share (63%) of the total growth in world consumption of petroleum and other liquid fuels from 2010 to 2040. It is very much imperative to find out alternative fuels for transportation sector as this sector is emitting about 22% GHG emission [8].

The International Energy Agency (IEA) forecasts that the emissions of carbon dioxide (CO_2) from transport sector will increase by 92% between 1990 and 2020 and it is estimated that 8.6 billion metric tons carbon dioxide will be released to the atmosphere from 2020 to 2035 [4].

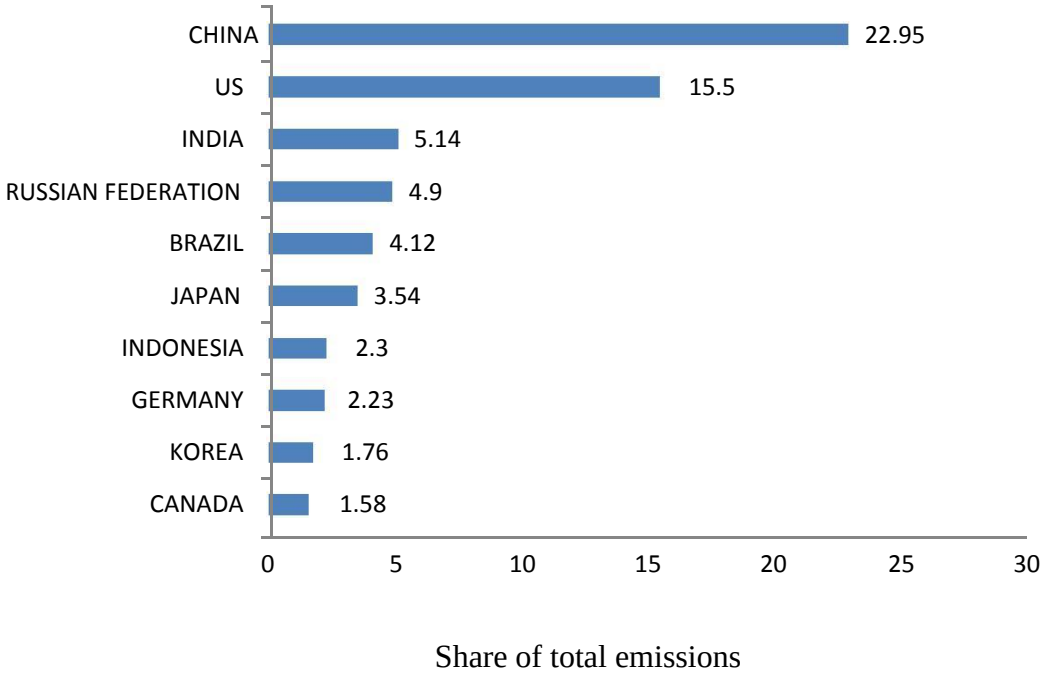

Figure 1 - Top Ten CO_2 Countries in the world (Data Source: M. Mofijur et al. 2015) [8]

Recently, interest has been created to explore cleaner alternative fuels from renewable sources to decrease the noxious emission to air and to reduce the reliance on the conventional liquid fuels.

1.2 Renewable Fuels

Biofuels are considered as a cleaner fuel for internal combustion engines in the transportation sector due to their renewable property and reduction of fossil CO_2 discharge which significantly contributes to the global climate

changes. The most feasible cleaner fuel for vehicles being considered globally is biofuels such as biodiesel and ethanol [8].

The utilization of biofuels is projected to increase from 1.3 million barrels of oil equivalent per day in 2012 to 4.6 million barrels of oil equivalent per day in 2040, and their share will be approximately 8% of road-transport fuel demand [3].

Biofuels, such as biodiesel and alcohol-based ethanol, methanol, butanol, and pentanol from renewable sources, are attractive alternative solutions to meet the energy demand and to regulate emissions. Owing to its renewability, biodegradability, and superior fuel properties to diesel, biodiesel is currently considered a future alternative for diesel fuel. Interests are growing on how to improve fuel properties and to overcome the problems. Although the utilization of alcohols enriched with oxygen content improves both the premixed and diffusive burning stages, their low Calorific Value (CV), low Cetane Numbers (CNs), miscibility and stability issues, weak auto ignition quality, and improper lubricating behavior limit their use as a pure diesel engine fuel [4].

For these reasons, bio-fuels (liquid and gaseous) have been subject to intensive research work all over the world because they are extraordinarily attractive alternative fuels. Biodiesel (liquid fuel) is nontoxic, renewable, and biodegradable, and is the most promising alternative energy for diesel engines [1].

1.3 Natural Gas

Natural gas (NG) is an interesting alternative to conventional liquid fuels (i.e., gasoline and diesel) for use in automotive engines. It is a mixture of various hydrocarbon molecules with methane as a main constituent. NG also contains heavier hydrocarbons such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}), and inert diluents such as molecular nitrogen (N_2) and carbon dioxide (CO_2). Sulphur compounds and other hydrocarbon species are also available within NG. The levels of these species strongly depend on the geographical source, time of year, and treatments applied during production or transportation (McTaggart-Cowan et al., 2006; Economides and Wood, 2009; Korakianitis et al., 2011; Paykani et al., 2012). In addition, NG is a clean burning fuel compared to diesel or gasoline. It has a high octane number, and therefore it is suitable for high compression ratio engines. It has a high self-ignition temperature, thus it need intense source of ignition energy to enable combustion [2].

2. STATE OF THE ART – CURRENT PRACTICES

Recently in all over the world research has been carried for exploring the alternative fuels due to rising market price of conventional fuels and shortage as well. Different fuels are being tested and researched in internal combustion engines to serve the same purpose. Although conventional fuels and biofuels are exhaustively researched and found many problems like Green House gases emissions, NO_x, PM, carbon deposit etc. Therefore

burning issue is to reduce the above factors and simultaneously modifying the engine to operate with a mix of gaseous fuels and pilot injection with diesel and biodiesel as well. Several researchers have performed tests on engines under different operating parameters which are discussed as under.

Seung Hyun Yoon et al. [1], experimented to study the influence of dual-fuel combustion characteristics on the exhaust emissions and combustion performance in a diesel engine fueled with biogas–biodiesel dual fuel. In their work, the combustion pressure and the rate of heat release were evaluated under various conditions in order to analyze the combustion and emission characteristics for single-fuel (diesel and biodiesel) and dual-fuel (biogas–diesel and biogas–biodiesel) combustion modes in a diesel engine.

Bo Yang et al. [3], investigated in dual-fuel mode engine and extensive experiments were conducted to investigate the effects of natural gas injection timing on the combustion and emissions performance under different pilot injection pressure and timing at low load conditions. The results indicated that retarded natural gas injection timing can achieve improved combustion performance and exhaust emissions at low load.

Jie Liu et al. [5] studied the effects of pilot fuel quantity and injection timing for CNG / diesel dual fuel engines. In their study, the emission characteristics of a CNG–diesel dual fuel engine with different pilot diesel fuel quantity and optimized pilot injection timing were investigated. They exhibited that the dual fuel mode reduces NO_X emissions by 30% averagely

in comparison to diesel mode. Also they showed that the PM emission is increased with the increase of the pilot fuel quantity.

Mohand Said Lounici et al. [6], used natural gas in compression ignition engines as supplement to liquid diesel in a dual fuel combustion mode and found to be a promising technique. They had done experiments at moderate and relatively high loads and found very interesting behavior of dual fuel operating mode in comparison to conventional diesel, both for engine performance and emissions. They had also shown a simultaneous reduction of soot and NO_X species over a large engine operating area.

G.P. McTaggart-Cowan et al. [7], investigates the implications of natural-gas composition on the combustion in a heavy-duty natural-gas engine and on the associated pollutant emissions. Their results indicated that the additives had no significant effect on the engine's power or fuel consumption. Also, they found that emissions of unburned fuel are reduced for all additives through either enhanced ignition or combustion processes. Black carbon particulate matter emissions were increased by ethane and propane.

Kyunghyun Ryu [9] investigated combustion and emissions characteristics of a compression ignition engine with a dual fuel (biodiesel–CNG) combustion system. This experiment utilized a biodiesel pilot injection to ignite a main charge of compressed natural gas (CNG). They found that overall performance of diesel single fuel combustion (SFC) still exceeds that

of biodiesel–CNG DFC. Biodiesel–CNG DFC results in relative high CO and HC emissions at low load conditions due to the low combustion temperature of CNG but no notable trend of HC emissions with variations of pilot injection timing were discovered.

Zhongshu Wang et al. [10], reveals that brake thermal efficiency and exhaust emission issues are still not fully-resolved to diesel/natural gas dual fuel engines. To better understand the effect of pilot diesel ignition mode on combustion and emissions characteristics of dual fuel engines, a detailed study concerned with varying diesel injection pressure may be useful. Satisfactory results can be obtained with higher brake thermal efficiency (35%), lower NO_X (60 ppm) and THC (0.4%) emissions.

Panayiotis Tsaousisa et al. [11], found from their experimental study that the raw oil from micro algal biomass can behave as a direct substitute fuel in an internal combustion engine. Based on the fuel properties of the algal oil, the performance and emission characteristics of a diesel engine running with this fuel were investigated using the software Diesel-RK. Algal oil demonstrated lower engine power output and NOx emissions compared to croton oil, whereas at the same time it showed higher break specific fuel consumption, particulate matter and CO_2 emissions.

Yanan Xu et al [12], explores an alternative method of utilizing the energy content of microalgae through the preparation of wet algal biomass slurry/fossil diesel emulsions for direct injection diesel engine

combustion. Engine exhaust emissions of nitrogen oxides (NOx) and particulate matter were lower for all of the wet algal slurry/diesel emulsions relative to a reference fossil diesel tested under similar conditions, while in the case of the emulsion prepared from algal biomass to which a flocculating agent had been added, emissions of carbon monoxide (CO) were found to increase significantly.

Qing Dong et al [13] evaluated the effects of different demineralization processes on the pyrolysis behavior and pyrolysis product properties of raw/torrefied rice straw. The results indicated that demineralization processes improved the fuel characteristics. Compared with raw rice straw, the effects of demineralization processes on the changes of cellulose crystallinity of torrefied rice straw can be ignored. All the demineralization processes enhanced the bio-oil yield at the expense of biochar and non-condensable gases for raw/torrefied samples. The obtained results can be helpful for understanding the pyrolysis behavior of raw/torrefied rice straw after different demineralization processes and for further utilization of biomass resources with high contents of silica and potassium.

Oladapo Martins Adeniyi et al [14] reveals that an algal feedstock or biomass may contain a very high oil fraction, and thus could be used for the production of advanced biofuels via different conversion processes. The overall potential for algae applications generally shows that this feedstock is still an untapped resource, and it could be of huge commercial benefits to the global economy at large because algae exist

in millions compared to terrestrial plants. Biofuels derived from algae have no impact on the environment and the food supply unlike biofuels produced from crops. The algae can be a substantial substitute of fossil fuel as a potential feedstock with diverse benefit for the resolution of the global energy demand, and environmental pollution control of GHG.

Green House gases such as CNG, PNG, Biogas etc. have been used in engines by various researchers to obtain clean combustion but rare studies are available indicating the studies on performance of engine with blend of green gaseous and liquid fuels.

In the proposed study an effort will be made to fill this gap and conduct a comprehensive experimental study on the performance of the engine running on various liquid – gaseous green fuels with different variables.

3. OBJECTIVES

The specific objectives of the proposed research work are summarized as follows:

(i) To perform trans-esterification on selected seed oils and characterize the obtained fuel.

(ii) To perform pyrolysis and gasification for biomass conversion into liquid and gaseous fuels.

(iii) To perform the tests on CI engine with blending of green gas and liquid fuel in different proportions with varying operating parameters such as load, compression ratio and exhaust gas recirculation.

(iv) To study the impact of varying injection pressure on the performance of engine.

(v) To conduct CFD simulation for setting of liquid injection parameters and of gaseous fuel metering and validate the model with real life model.

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